Challenges and Opportunities for Low-Carbon Buildings

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ABSTRACT

Buildings are responsible for higher greenhouse gas emissions than any other sector of society. Furthermore, the portion of emissions due to building construction and operation has been increasing in recent decades. These emissions are primarily due to heating, cooling, and lighting, though the embodied emissions in materials are also significant. Major new initiatives are underway to reduce the energy consumed by buildings, but there are numerous technical, economic, and policy barriers. This paper summarizes some of the key challenges for the design and implementation of future low-carbon buildings in the United States, and identifies opportunities for the engineering professions. More efficient building design represents one of the most cost-effective opportunities for large-scale carbon reductions on a national and global scale. A greater emphasis on integrated building design for the full life cycle can lead to dramatically improved building performance. Finally, a series of recent projects demonstrate successful life cycle design for low-carbon buildings.

Introduction

This paper outlines some of the key challenges facing the engineering of low-carbon buildings. Though buildings have major environmental impacts due to water use, raw material consumption, and other natural resource depletion, it is useful to focus on greenhouse gas emissions due to the central role of buildings in mitigating climate change. In particular, carbon dioxide equivalent (CO_2e) provides a simple metric for building environmental performance. As the largest source of carbon emissions in the United States, buildings also represent a significant opportunity (Fig. 1). The Intergovernmental Panel on Climate Change (IPCC) has identified buildings as the sector offering the greatest potential for carbon reductions (IPCC, 2007). Similarly, the World Business Council for Sustainable Development (WBCSD) has demonstrated that global energy use of buildings could be reduced 60% by 2050 using existing technologies (WBCSD, 2009). McKinsey Consulting has identified the building sector as the most cost-effective strategy for carbon abatement, with most building improvements providing carbon reductions at a negative cost (McKinsey, 2007). In short, there are a range of strategies in the building sector to save both money and carbon emissions. Clearly engineers have a major role to play in helping to reduce the carbon emissions of existing and new buildings, though a number of challenges exist.

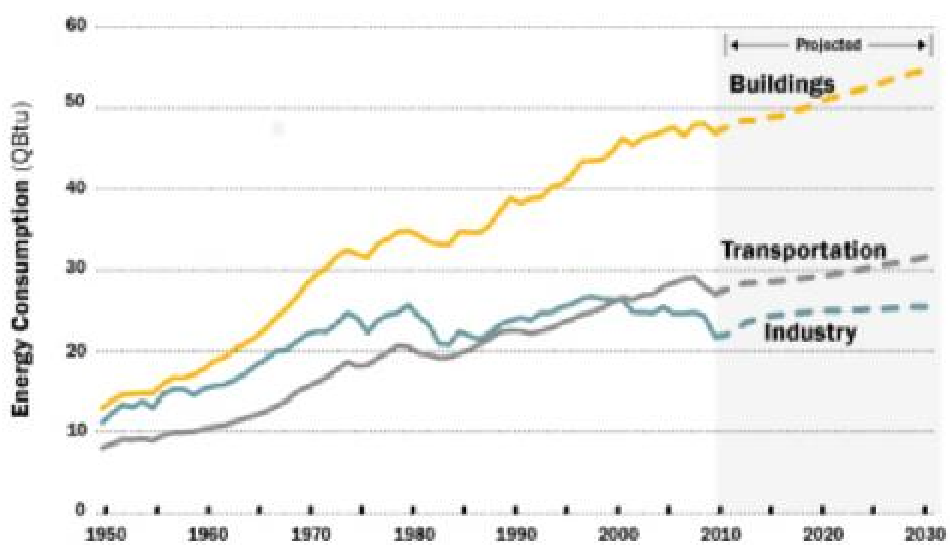

Fig. 1. U.S. Energy Consumption by Sector (Source: Architecture2030/EIA)

Several current initiatives in the United States provide targets for improved carbon performance of buildings. The *2030 Challenge* establishes targets for carbon reductions of new buildings, with increasing standards in the coming two decades (Architecture 2030, 2011). The current aim is to design buildings to use 60% less energy than average for the building type. The reduction target increases by 10% every five years (e.g., lowering to 70% reductions by 2015), until carbon-neutral buildings are the target in the year 2030. These design goals are to be met through three primary approaches: 1) improved design strategies; 2) more efficient technologies and systems; and 3) off-site renewables (up to a maximum of 20%). While the *2030 Challenge* is voluntary at present, many leading engineering firms have committed to pursuing its goals, and a number of architecture firms are now tracking the energy consumption of their new buildings in relation to the *2030 Challenge* goals. Other countries in the world have binding legal requirements to achieve dramatic carbon reductions in new buildings in the coming decade, though the closest legal target in the United States is California's Assembly Bill 32 (AB32), which mandates reductions to 1990 emissions levels by 2020 (Assembly Bill 32, 2011). Such policies, as well as more stringent building codes, can serve as important motivators for engineers and architects.

Challenges for Low-Carbon Buildings

While engineers play a crucial role in the design of more sustainable buildings, they often get involved too late in the design process. Many of the key decisions are taken in the earliest design stages, when building orientation, glazing ratio (area of glass/area of opaque wall), and the overall form of the building are decided. Once these critical decisions have been made, engineers can attempt to optimize a poor design, but it is difficult to arrive at low-carbon design without having engineers involved in the initial design. The challenge is to integrate engineering analysis in a manner that provides rapid feedback to architects and the rest of the design team early in the process. This requires engineers who are trained as designers, and can pose multiple solutions to open-ended problems. In short, the design of high-performance buildings requires integrated, systems thinking from the earliest conceptual design stage.

There is a need to train more engineers in the fields of building science and sustainable design. In particular, most engineering schools do not directly address the design and operation of buildings, since the field of sustainable building design falls between the disciplines of mechanical engineering, civil engineering, and architecture. Though there are a small number of programs in architectural engineering, the number of architectural engineering graduates nationally is much lower than traditional engineering disciplines, and the coming decades will require more engineers in this field. Despite the dramatic economic and environmental impact of buildings, the engineering of sustainable buildings is missing from most schools of engineering in the United States.

Finally, there is an acute lack of spending on research and development (R&D) for sustainable buildings. Compared to other sectors such as the automobile or electronics industries, the construction industry does not spend nearly as much on R&D. It has been estimated that only 0.25% of gross sales in construction are spent on R&D in the United States (Gould and Lemer, 1994). Furthermore, only 0.2% of federal research funding is spent on topics related to green buildings (USGBC, 2008). The scarcity of research funding means that fewer researchers are working on the vital topic of sustainable building technology, despite the pressing urgency of climate change and the favorable economics for carbon reductions through improved buildings.

Opportunities for Low-Carbon Buildings

The key to improved building performance is integrated design, which incorporates systems thinking at the conceptual design stage. Decisions about building orientation, façade systems, heating and cooling strategies, and glazing ratios play a crucial role in the final energy performance of the building. Building design must be climate-specific, and should be tailored to the regional climate. The choice of materials plays a central role in the embodied carbon of any building, and also has implications for the carbon emissions due to the operation of buildings, through thermal mass. However, most traditional architectural design software does not include the capacity to analyze energy or environmental performance. In the last decade, several tools have been developed to aid architects and engineers in the early design stage. One example is the MIT Design Advisor, which allows for the rapid estimation of building energy use based on massing, orientation, climate, glazing ratios, and more (MIT, 2011). More recently, the DIVA platform has been developed to allow architects to run basic performance simulations in the early design stage within existing architectural design software (DIVA, 2011). In order to influence the initial design phase, these programs provide rapid feedback to architects. Though such programs are developing quickly, there is still an urgent need for improved design software as well as engineers capable of systems level building design.

A multidisciplinary education focusing on sustainable design can attract a new generation of engineers to the profession. In addition to engineering expertise in heat transfer, thermal science, materials engineering, and other traditional building science disciplines, sustainable buildings require expertise in design thinking and creative problem solving. Furthermore, there is demand in the market for increased literacy in rigorous sustainability metrics, and for expertise in life-cycle environmental and economic performance of buildings. Integrated graduate education in the built environment, such as the "Solving Urbanization Challenges by Design" program at Columbia, which combines engineering, architecture, and planning, can help to provide the broad education needed for sustainable building designers and researchers (IGERT, 2011).

To increase R&D funding for sustainable buildings, new partnerships are required between industry, academia and government. The Concrete Sustainability Hub at MIT is one example of such a partnership, which is advancing our knowledge of the environmental performance of buildings through rigorous life cycle assessment (LCA) of the carbon emissions of buildings. From federal sources, the National Science Foundation (NSF) is a particularly appropriate venue for greater research funding in sustainable buildings. A number of NSF Graduate Research Fellowships could be established for students working in building science, which would help to attract more researchers to the field.

Case studies

Many significant low-carbon buildings have been constructed in recent years, which can serve as inspiration for engineers and architects. Some noteworthy examples for a range of different building types include:

- Residential Building: BedZED, Beddington, England
- School: Richardsville Elementary School, Richardsville, Kentucky
- Office Building: National Renewable Energy Laboratory (NREL), Golden, Colorado
- Cultural Building: Mapungubwe Visitor's Center, South Africa

In these and most other cases of sustainable buildings, the crucial design strategies were developed by a collaborative team of architects and engineers early in the design process. By setting clear targets for energy consumption, these designs were achieved at similar costs as conventional construction, with significant life-cycle economic benefits due to reduced operating energy requirements. These and other projects demonstrate that the technology for carbon neutral buildings exists today.

Conclusions

Buildings are widely recognized as the largest opportunity for cost-effective carbon reductions in the United States and around the world. While engineers have a vital role to play in transforming the built environment into a low-carbon future, there are numerous areas for improvement. In particular, a new emphasis on conceptual design, life cycle thinking, and innovative research partnerships can help to advance the field, reduce carbon emissions, and train a new generation of engineers.

References

Assembly Bill 32, (2011), California Global Warming Solutions Act, Available online at www.arb.ca.gov/cc/ab32/ab32.htm

Architecture2030, 2011. Available online at http://www.architecture2030.org/2030_challenge/the_2030_challenge.

DIVA (2011). Available online at www.diva-for-rhino.com.

IGERT (2011). Columbia University IGERT Program, Solving Urbanization Challenges by Design. Available online at http://www.civil.columbia.edu/igert/index.html

IPCC (2007). "IPCC Fourth Assessment Report: Climate Change 2007 (AR4)". Cambridge, United Kingdom and New York, NY, USA.: Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

McKinsey (2007). "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" McKinsey and Company, U.S. Greenhouse Gas Abatement Mapping Initiative. http://www.mckinsey.com/en/Client_Service/Sustainability/Latest_thinking/~/media/McKinsey/dotcom/client_service/Sustainability/PDFs/Reducing%20US%20Greenhouse%20Gas%20Emissions/US_ghg_final_report.ashx

MIT (2011). Design Advisor, Building Technology Program. Available online at http://designadvisor.mit.edu

WBCSD (2009). "Energy Efficiency in Buildings: Transforming the Market," World Business Council for Sustainable Development. Available online at http://www.wbcsd.org/DocRoot/Ge2Laeua8uu2rkodeu7q/91719_EEBReport_WEB.pdf

Gould, J.P. and A.C. Lemer, (1994) "Toward Infrastructure Improvement: An Agenda for Research, National Academies Press, 1994.

USGBC (2008). A National Green Building Research Agenda, United States Green Building Council (USGBC) Research Committee, April 2007, Revised February 2008. Available online at http://www.usgbc.org/ShowFile.aspx?DocumentID=3402